

## **STRUCTURAL ELEMENT AND PROCESS FOR ITS PRODUCTION**

### **Cross-reference to Related Applications**

**[0001]** This is a continuation of application number 09/349,014 filed July 7, 1999, which claims priority on Swiss application 1197/99 filed June 28, 1999, which priority claim is repeated here.

### **FIELD AND BACKGROUND OF THE INVENTION**

**[0002]** The present invention relates in particular to the field of semiconductor industry and in particular to the field of "Assembling and Packaging (A+P)".

**[0003]** It is emphasized, however, that the present invention can also be applied to other fields where it is desired to realize electrical bond connections on copper surfaces.

**[0004]** Therefore, if the present invention is described in the context of the semiconductor industry the invention should not be understood as to be limited to that field. The same problems occur in other fields and the invention can equally be applied therein.

**[0005]** It is common in the semiconductor industry to connect two or more parts, by bonding or by the so-called process of "wire bonding." One of the parts is customarily a wire and/or comprised of aluminum. The "wire bonding" of parts

to form aluminum oxide layers at standard atmosphere is well known in the art. To establish a high quality intermetallic connection between metals, such as between aluminum and gold, where such connection has the lowest possible electrical resistance and is stable and electrically and mechanically reliable, it is necessary to create the connection while heating the parts to at least 80°C, or preferably higher.

**[0006]**        However, it is well known that aluminum is not a preferred metal for conducting electricity.

**[0007]**        Copper provides a substantially better electrical conductivity and the possibility of smaller dimensioning of current-conducting parts, such as metallic conductors on chips and wire contacts. A great need exists, in particular in the semiconductor industry, to use electrical contact junctions bonded with current-conducting copper parts, as disclosed in Terrence Thompson, "Copper IC Interconnect Update", HDI, Vol. 2, No. 5, May 1999, p. 42.

**[0008]**        However, problems present with the prior art metal bonding processes for copper-gold wire bond systems exist, as disclosed in George G. Harmann, "Wire Bonding in Microelectronics", McGraw-Hill, 1997, pp. 138-140.

**[0009]**        This publication explains (on p. 171) why the bonding of aluminum is relatively free of problems, specifically because a hard brittle oxide layer is formed on it which is forced open through the bonding process. In comparison, softer oxides such as copper and nickel oxide would reduce the capacity for bonding.

**[0010]**        Table I-3 "Reversing the Bonded Metallurgical Interface" (p. 128) of the Harmann publication also reveals in principle that hard oxides on soft metals facilitate bonding. This is consistent with the disclosures on pp. 197, 198,

according to which it is established that during the bonding, brittle films are forced open and flushed into so-called "disposal zones". This permits establishing satisfactory ultrasonic and thermionic bond connections through relatively thick layers. The bondability through 2.5 nm CVD deposited oxides is described as being unchanged compared to the bondability of pure contact pads.

**[0011]** In summary, with respect to the semiconductor industry, the bonding of aluminum to copper in the case of conductors permits a further miniaturization of the chips. The fabrication process of chips with copper conductors is well known. Difficulties occur if bond connections of copper contacts of the chips are to be realized to the "chip carrier" (wire bonding, flip-chip technique). In contrast to the aluminum oxide forming on aluminum, which is a hard, thin, oxygen-blocking layer which protects the subjacent metal against further oxidation or contamination at the conventional temperatures during the wire bonding, copper oxide is soft and permits neither the sudden breakthrough during bonding, as does the aluminum oxide, whereby a flux-free welding or soldering connection can be established. Nor does copper oxide form an oxygen diffusion barrier at bonding temperatures.

### **SUMMARY OF THE INVENTION**

**[0012]** The present invention proposes a structural element, and the process for making the same, with at least one connection having at least one metal part comprising substantially copper and a second part comprising a metal. The connection is mechanically and electrically faultless. For this purpose, structural elements according to the invention are disclosed. Preferred embodiments of these structural elements are also claimed.

**[0013]** The second part of the structural element can also, at least substantially, comprise copper, or preferably comprises substantially gold or aluminum. The second part is coated according to the described manner.

**[0014]** According to the invention, the copper part(s) (if two copper parts are to be connected by bonding) is coated with a hard layer which is stable at a temperature of at least 80°C. An oxygen diffusion barrier is formed at this temperature at least approximately as well, if not better, than would an aluminum oxide layer which forms on aluminum in a standard environment. The two parts are connected by means of bonding while heating them to at least 80°C. The further preferred embodiments analogously also apply to the structural elements according to the invention.

**[0015]** According to another feature of the invention, a layer is deposited on the two parts to be bonded. The layer is preferably stable at a temperature of at least 100°C, more preferably up to at least 150°C, and even more preferably up to at least 300°C. The bonding process occurs with the heating of the bonded parts to at least said temperature. However, this does not mean that if the layer is stable even at high temperatures, for example, 350°C, the bonding also occurs at this temperature. Bonding can also occur at lower temperatures, but at least at 80°C, preferably at least at 150°C, even more preferably at least at 200°C.

**[0016]** In a further preferred embodiment, the deposited layer has mechanical and thermal properties as well as oxygen diffusion behavior, which is at least approximately equivalent to, if not better than, those qualities of an aluminum oxide layer which forms on aluminum in a standard environment.

**[0017]** In view of the preferred application field, namely the semiconductor technology, at least one of the parts is structured as a wire and the method of "wire bonding" is used.

**[0018]** Furthermore, the layer is deposited as an electrically conducting or as an electrically insulating layer. Its property in this regard can positively be utilized, i.e., the layer can be used as insulation or conductor layer.

**[0019]** The following materials or mixtures thereof are preferable as materials for said layer:

- a)  $\text{SiO}_x$  with  $1.5 \leq x \leq 2$ , preferably with  $1 < x < 2$ ,
- b) TaSiN, preferably  $\text{Ta}_x\text{Si}_y\text{N}_z$  with
$$35 \leq x \leq 55$$
$$12 \leq y \leq 18$$
$$32 \leq z \leq 48, \text{ with } x + y + z = 100,$$
in particular preferred



- c) TiN
- d) AlO
- e) TiSiN
- f) TaN
- g) SiN, preferably  $\text{Si}_3\text{N}_4$
- h) WSiN
- i) ReO
- k) PdO
- l) ZrO
- m) YO
- n) ZrN
- o) NbN
- p) VN

q) if need be CuN.

**[0020]** Said layer is further preferably deposited in a vacuum deposition process such as, for example, in a CVD, a PVD, a PECVD, a PEPVD process or through plasma polymerization.

**[0021]** Depending on the history of the involved part, substantially comprising copper, it is further proposed to purge it before depositing the layer, preferably by treatment with a hydrogen plasma or in a hydrogen-nitrogen plasma.

**[0022]** It is further preferred to deposit the layer at a thickness  $d$  of at least 1.5 nm, preferably of at least 2.0 nm, in particular in a range of  
 $2.0 \text{ nm} \leq d \leq 15 \text{ nm}$ , in particular at  
 $2.5 \text{ nm} \leq d \leq 3.5 \text{ nm}$ .

**[0023]** The thickness of the layer is limited towards the bottom by the requirements made of it as oxygen diffusion barrier. Towards the top, the thickness to be provided is primarily limited by the capacity of forcing open the bonding to be carried out.

**[0024]** In order to optimize the required effect of the layer as an oxygen diffusion barrier, it is further proposed to implement the layer so as to be amorphous under X-rays or glass-like. This requirement also defines a lower limit for the layer thickness  $d$ , which can consequently not be implemented as atomic monolayer or, in this case, would no longer be oxygen-tight. Furthermore, the layer can comprise a material with oxygen getter effect, for example, a substoichiometric oxide, in particular  $\text{SiO}_x$  with  $x < 2$ .

**[0025]** In view of the possibility of implementing the layer provided according to the invention as an electrically conducting or electrically insulating layer, the layer as a conductor layer or an insulation layer.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0026]** The invention will subsequently be explained by example in conjunction with tests and their results, as well as with reference to Figures. Therein depict:

Fig. 1 is a graph plotting the shear strength of a bond connection through an  $\text{SiO}_2$  layer with the thickness of a copper layer deposited electrolytically with a 1  $\mu\text{m}$  thickness or by sputtering a layer with 500 nm thickness; and

Fig. 2 is a schematic of a bond connection provided on the structural element according to the invention; and

Fig. 3 is a view similar to Fig. 2 of an intermediate step in the process of the invention.

### **DESCRIPTION OF THE PREFERRED EMBODIMENTS**

**[0027]** A wafer coated with a copper layer acts as the substrate for tests using the claimed process. The copper layer has thicknesses of 500 nm and 1000 nm.

**[0028]** Thinner copper layers in the approximate range of 500 nm were deposited by means of sputtering. Thicker copper layers in the range of 1,000 nm were deposited electrolytically. In some experiments, a purging of the

copper surface was carried out in a hydrogen plasma. However, it was found that surface purging did not result in an increase of the tensile loading capacity compared to wafers with identical coating in which no purging was carried out. Consequently, the need for a preferred purging cannot be demonstrated experimentally. However, consideration should be given to the fact that under production conditions, the copper surfaces are exposed to diverse environmental conditions and that in all probability it is entirely advantageous to carry out said purging step before the deposition of the layer according to the invention and be such in order to create identical starting conditions for the coating.

**[0029]** A multiplicity of different materials with different layer thickness were studied and each bonded at different bonding temperatures onto gold wires with a diameter of 1.0 mil.

**TABLE 1**  
**Layer (thickness in nm)**

NO.	SiO <sub>2</sub> (1)	SiO(H) (2)	SiN(H) (3)	Si <sub>3</sub> N <sub>4</sub> (4)	CrO <sub>2</sub> (5)	Nb <sub>2</sub> O <sub>5</sub> (5)	Ta <sub>45</sub> Si <sub>15</sub> N <sub>40</sub> (7)	TiN (8)
d	3nm 7nm	3nm 7nm	3nm 7nm	3nm 7nm	3nm 7nm	3nm 7nm	3nm 7nm	3nm 7nm
40°C	v v	v v	v (v)	v (v)	v (v)	v (v)	v (v)	v (v)
200°C	v v	- -	- -	v v	- -	- -	v (v)	v (v)

"v" - bondable

"(v)" - limited bondability

"-" - not bondable

**[0030]** Table 1 summarizes the results for the eight listed hard layer materials No. 1 to No. 8 each at two layer thicknesses and tested at the bonding temperatures of 40°C and 200°C. At bonding temperatures of 200 °C targeted for the above stated reasons, only SiO<sub>2</sub>, Si<sub>3</sub>N<sub>4</sub>, Ta<sub>45</sub>Si<sub>15</sub>N<sub>40</sub> and TiN lead to bondability. Layer



thicknesses in the range of 3 nm tend to yield better bondability than greater layer thicknesses. At temperatures below 60°C, at which the copper oxidation is of no significance, only the layer hardness in connection with its thickness  $d$  appears to be critical. The layer must not be too thick or otherwise it cannot be broken through during the wire bonding. At increased temperatures above 80°C, the soft greasy copper oxide is formed and a layer that is only brittle and hard of corresponding thickness is no longer sufficient. The layer must be capable of effectively preventing the oxidation of the copper at bonding temperatures, with which at higher temperatures the effect of the layer applied according to the invention as an oxygen diffusion barrier becomes increasingly important.

**[0031]** In Table 2 the deposition and the essential process conditions for the layers No. 1 to 8 according to Table 1 are summarized.

**TABLE 2**

No.		
(1)	Deposition by sputtering	Si target, Ar/O <sub>2</sub> mixture 3 x 10 <sup>-3</sup> mbars
(2)	Plasma polymerization	dimethyl diethoxy silane Si(CH <sub>3</sub> ) <sub>2</sub> (OC <sub>2</sub> H <sub>5</sub> ) <sub>2</sub> , 10 <sup>-2</sup> mbars
(3)	Deposition by sputtering	Si target, Ar/N <sub>2</sub> mixture 10 <sup>-2</sup> mbars
(4)	Ion plating	Si vaporization, Ar/N <sub>2</sub> mixture 5 x 10 <sup>-3</sup> mbars
(5)	Deposition by sputtering	Cr target, Ar/O <sub>2</sub> mixture 5 x 10 <sup>-3</sup> mbars
(6)	Deposition by sputtering	Nb target, Ar/O <sub>2</sub> mixture 4 x 10 <sup>-3</sup> mbars
(7)	Deposition by sputtering	Ta-Si target, Ar/N <sub>2</sub> mixture 5 x 10 <sup>-3</sup> mbars
(8)	Ion plating	Ti vaporization, Ar/N <sub>2</sub> mixture 5 x 10 <sup>-3</sup> mbars

**[0032]** Subsequently strip-off tests were carried out on the successfully bonded connections with the layers No. 1, 4 and 7 according to Table 1.

**[0033]** The results show that only those layers exhibit good mechanical behavior which are stable at the bonding temperature which, in any case, is greater than 80°C and, as shown, is 200°C. Suitable are primarily layers which are stably amorphous (amorphous under X-rays with crystal sizes  $\leq 3$  nm) and at said temperatures preferably remain stable even to 300°C. Apart from the materials No. 1, 4, 7, 8 of Table 1, among them are also TiN, further SiO<sub>x</sub> (substoichiometric

silicon oxide) aluminum oxide (preferably substoichiometrically), TiSiN, TaN, WSiN, ReO, PdO, ZrO, YO, ZrN, NbN, VN, if need be also CuN.

**[0034]** By using substoichiometric  $\text{SiO}_x$  or fundamentally a material with oxygen getter effect, for example a substoichiometric oxide, the effect of the layer material as oxygen diffusion barrier can be increased.

**[0035]** In Table 3, shown below, the resulting tensile loading capacities of the resulting bond connections according to experiments No. 1, 7 and 4 are summarized.

**TABLE 3**

Hard Layer	Thickness d in nm	Strip-off force in g	No.
$\text{SiO}_2$	7	17,46	(1)
$\text{Ta}_{4,5}\text{Si}_{2,5}\text{N}_3$	3	14,7	(7)
$\text{Si}_3\text{N}_4$	3	14,2	(4)

**[0036]** In Fig. 1, as a function of the deposited layer thickness for a  $\text{SiO}_2$  layer, with bonding at a temperature of  $200^\circ\text{C}$ , depending on the layer thickness d the resulting strip-off loading capacities are plotted of a copper layer of 1000 nm and one of 500 nm. The resulting bond connection becomes optimal and substantially independent of variations of d and the copper layer thickness with thin layer thicknesses of the hard layer.

**[0037]** Fig. 2 schematically shows a bond connection region on a structural element according to the invention. In particular, Fig. 2 depicts:

1: a substrate 1

- 2: a layer at least predominantly comprising copper
- 3: a further part, in particular wire 3, connected with the copper layer 2 through bonding and forming an intermetallic connection at 4
- 4: the hard layers provided according to the invention forced open through the bonding process in the region of the generated bond connection.

Fig. 3 uses the same reference numerals to denote the same parts and shows the step before the bonding step that results in the structure of Fig. 2.

With the present invention the utilization of current standard equipment for wire bonding continues to be ensured for copper technology, for example in the chip fabrication. This equipment operates at bonding temperatures far above 80 °C.